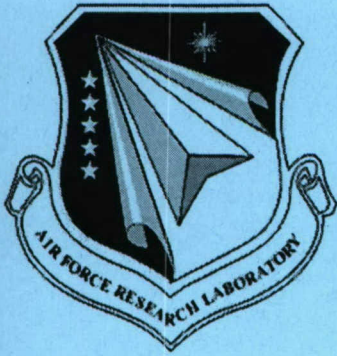AFRL-HE-WP-TR-2006-0132

Effects of Tactile and Audio Cues on Reducing Vestibular Illusions

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FOR THE DIRECTOR

//signed//

MARK M. HOFFMAN
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14. ABSTRACT
The effect of multisensory cues (3-D audio, tactile belt) to overcome a vestibular illusion in a rotating Barany Chair was investigated. Seated subjects were rotated about their spinal axis (Z axis) from a standing stop to a predetermined velocity. The acceleration experienced by the subjects as they changed velocity caused their semi-circular canals to react which they sensed as a rotation. When the chair was slowed, or stopped, the direction of the acceleration cue reversed and the subjects sensed a false rotation in the opposite direction. This illusion, called the somatogyral illusion, can occur in flight. The purpose of this research was to see if multisensory countermeasures could be applied to the subjects that would reduceor eliminate the false rotation. The 3-D audio countermeasure proved to be successful in reducing the velocity of the chair's rotation and the tactile belt countermeasure produced the highest success rating among the subjects.

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1.0 Summary

The effect of multisensory cues (3-D audio, tactile belt) to overcome a vestibular illusion in a rotating Barany Chair was investigated. Seated subjects were rotated about their spinal axis (Z axis) from a standing stop to a pre-determined velocity. The acceleration experienced by the subjects as they changed velocity caused their semi-circular canals to react which they sensed as a rotation. When the chair was slowed, or stopped, the direction of the acceleration cue reversed and subjects sensed a false rotation in the opposite direction. This illusion, called the somatogyral illusion, can occur in flight. The purpose of this research was to see if multisensory countermeasures could be applied to the subjects that would reduce or eliminate the false rotation. The 3-D audio countermeasure proved to be successful in reducing the velocity of the chair's rotation and the tactile belt countermeasure produced the highest success rating among the subjects.

2.0 Introduction

The tactile sensory system, the most primitive of the senses, is a "near" sense that requires some form of contact with the skin in order to function. Seeing, hearing, and smelling are "far" senses as they capture information from sources away from the body and at a distance. Recent research has shown success in improving situational awareness by converting touch into an apparent far sense by wearing vibrotactile stimulators or "tactors" (4, 15, 16, 17). For example, the Tactile Situation Awareness System (TSAS), a torso vest containing vibrating tactors, was effective in assisting the pilots in controlling both fixed and rotary winged aircraft in compromised flying environments (15).

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In situations where spatial disorientation may occur, for example, the somatogyral illusion, vibrating stimulators or tactors could help reduce the "false sense of rotation or lack of rotation when out of the cockpit visual cues are lacking as to a plane's motion, position, and attitude within the fixed coordinates provided by the earth's surface and the gravitational vertical" (3, 13). When the aircraft begins a slow yaw, the vestibular apparatus equilibrates and makes this spin appear "normal, i.e., straight and level." If the problem is realized and the spin is stopped, the vestibular system incorrectly signals a yaw in the opposite direction, resulting in the return of the aircraft back into the original spin.

Recently, a laboratory study investigated the effects of a vest containing 24 columns of vibrating tactors (two tactors in each column) circling the upper torso to reduce a simulated somatogyral illusion (4). When activated, the vest signaled direction and velocity of rotation. To generate this illusion a rotating chair was accelerated until maximum rotation of 120 deg/s was attained, and then abruptly stopped. During the next 40 s, all perceived rotations were to be nulled or cancelled by the subject by turning a control knob. Relying solely on "erroneous" vestibular signals, the chair was rotated in the same direction as the original spin, but at a rate of 50 deg/s. The application of tactile vibrations about the torso significantly reduced the rotation movement error, or cancellation error (CE), to 28 deg/s. CE is the root mean squared error of the angular velocity the subject indicated in attempting to cancel the perceived motion of the rotating chair. It was measured in deg/s. The task of canceling movement was made more difficult with the application of random movements or perturbations to the chair. The rationale for this procedure was to prevent "'smart' (cognitive) control of self motion" (4). Even with the significant reduction in the CE, this performance was assumed to be high in comparison with the CE when no illusion was created. Finally, motion sickness symptoms were assessed at the end

of the study by both verbal reports and observations and deemed minor to non-existent. However, motion sickness symptoms could have been generated during specific trials, for example, when vestibular signals were the only source for controlling rotation and the chair continued to spin over the 40 s periods. With only two such trials presented, stimulation may have been appropriate, but not sufficient to trigger significant motion sickness symptoms. More trials might exacerbate these symptoms.

With the questions raised by the previous study, one purpose of our research examined whether increased training and experimental sessions, and no perturbations, would further reduce the CE during the recovery phase of the illusion. Concerning motion sickness assessment, we investigated whether specific motion sickness symptoms might be coupled with selective experimental procedures, such as those trials where performance in canceling the rotation was at its worse. For these, rating of motion sickness symptoms after each trial would be enlightening. Further, assessment of motion sickness symptoms pre- and post-test would provide valuable information as to any changes in overall well-being.

Normally, the visual system, with eyes orientated forward, has limitations in azimuth, elevation, and distance. In the environment, three-dimensional (3-D) audio augments the visual system where gaze is automatically directed at a sound source. In an enclosed cockpit, virtual 3-D audio can be presented through stereo earphones (1, 2, 12). Three-dimensional audio, presented through stereo earphones, gives the illusion that sound is originating from an external point source. This virtual 3-D audio was used successfully to decrease target acquisition time and to improve situational awareness, speech intelligibility, and pilot workload. (12). Since 3-D audio and vision are coupled, we reasoned that in those situations where out-of-the-cockpit cues were absent, the illusory effects of changes in auditory azimuth would serve as an orienting

stimulus and thus a countermeasure. As with tactile stimulation traveling around the torso, "white noise" was presented and perceived as if it were circling the head with respect to chair velocity and direction of rotation.

3.0 Methods, Assumptions and Procedures

3.1 Participants

Ten men and women volunteered their participation. They ranged in age from 18 to 56 years, with a mean age of 38 years. Potential volunteers completed a self-report form identifying any physiological, neurological, and psychological factors that might preclude their participation in the study. The medical monitor was responsible for reviewing the pre-screening forms, subsequent participant approval, and being "on-call" during testing. The research protocol was approved in advance by the Institutional Review Board of Wright-Patterson Air Force Base. Each participant provided written informed consent before participating.

We replicated the protocol for chair rotation, perturbations, and cancellation knob procedures as described in Bos et al. (4).

3.2 Rotating Chair

Participants were secured in a Neuro Kinetics Inc (Pittsburgh PA) Barany Rotary Chair System chair with the accompanying harnesses for lap and shoulder restraints (Figure 1). The back of the head was supported to reduce self-initiated head movements. The chair was oriented in a vertical rotation mode with the participant's head at the center of rotation. The somatogyral illusion was generated by increasing the chair's rotation for 24 seconds with a constant acceleration of $5^\circ/\text{sec}^2$ to a velocity of $120^\circ/\text{sec}$. Upon reaching this velocity, the chair was brought to a quick standstill with a constant deceleration ($100^\circ/\text{sec}^2$) over a period of 1.2

seconds. Immediately, after a 0.8 s delay, the chair either remained stopped or followed one of

two different perturbation patterns (see Figure 2). The perturbation pattern was a disturbance
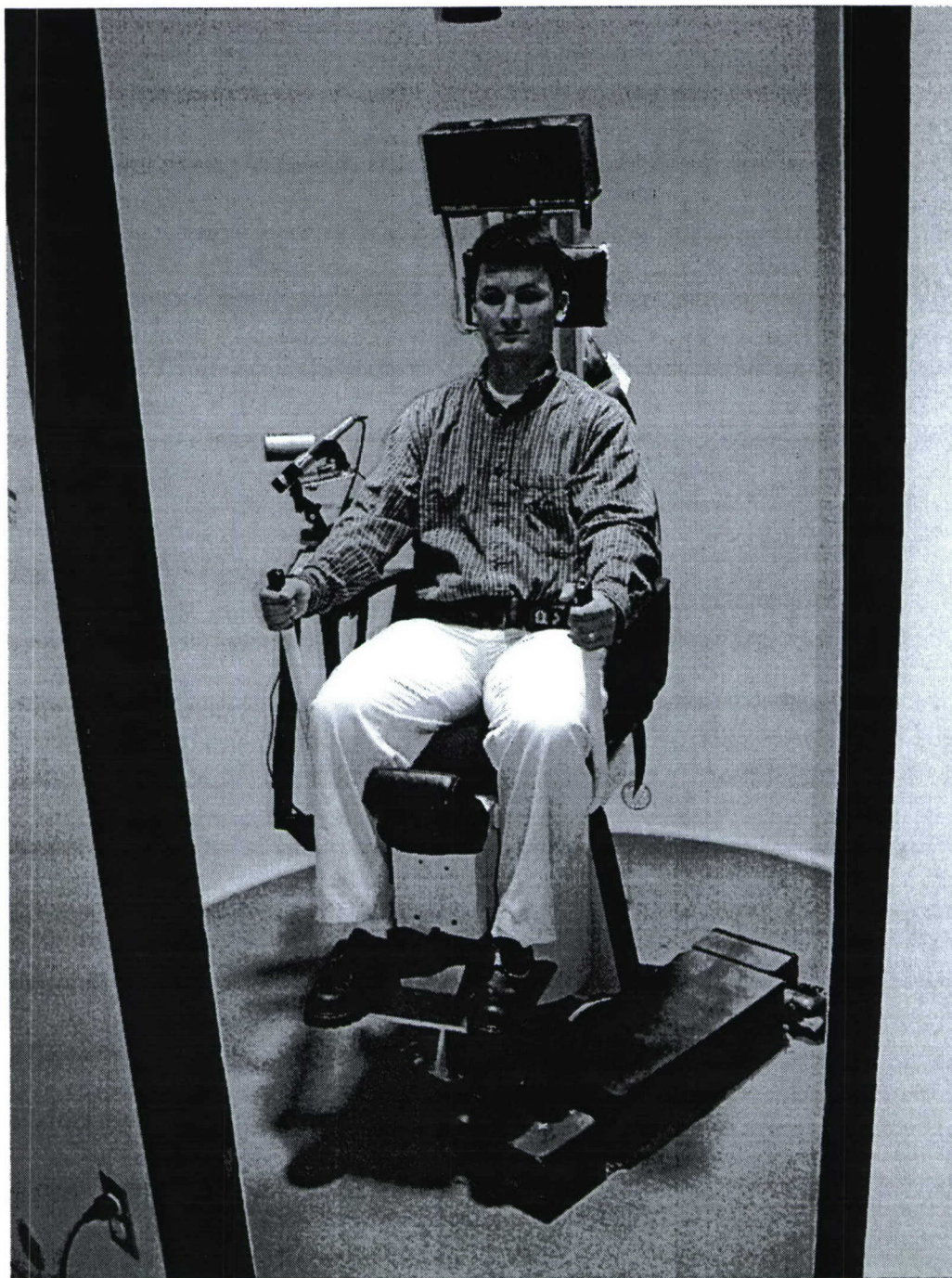
Figure 1. The Neuro Kinetics Inc Barany (Rotary) Chair System

stimuli consisting of the sum of 20 sinusoidal frequencies equally spaced from 0.02 Hz to 0.4 Hz, but at random phases (see reference 4 for additional details). The participant was required to cancel or null the actual or perceived rotations of the chair for a total of 40 s.

3.3 Cancellation Effect (CE) Control Knob

A 2.54 cm control knob was fastened to the right arm of the rotating chair. Prior to the start of each trial the participant adjusted the knob to center the rheostat to zero. When instructed, the participant rotated the cancellation knob to the left or right to nullify any perceived chair rotations. When random movements were presented, the corrections applied to the cancellation knob were added to or subtracted from the actual perturbations of the chair. The primary dependent variable was cancellation error (CE).

3.4 Tactile Belt

An elastic band 15 cm wide was fastened around the waist. A single row of 12 vibrotactile stimulators was secured with Velcro allowing for individual waist size while maintaining approximately 30 deg separations between the tactors. As the chair rotated, the participant simultaneously received vibratory stimulation around the waist. As the participant rotated either clockwise (CW) or counter-clockwise (CCW), the vibratory stimulation would indicate deviation from a stationary source, i.e., as the participant rotated to the left the vibrations progressed away or to the right.
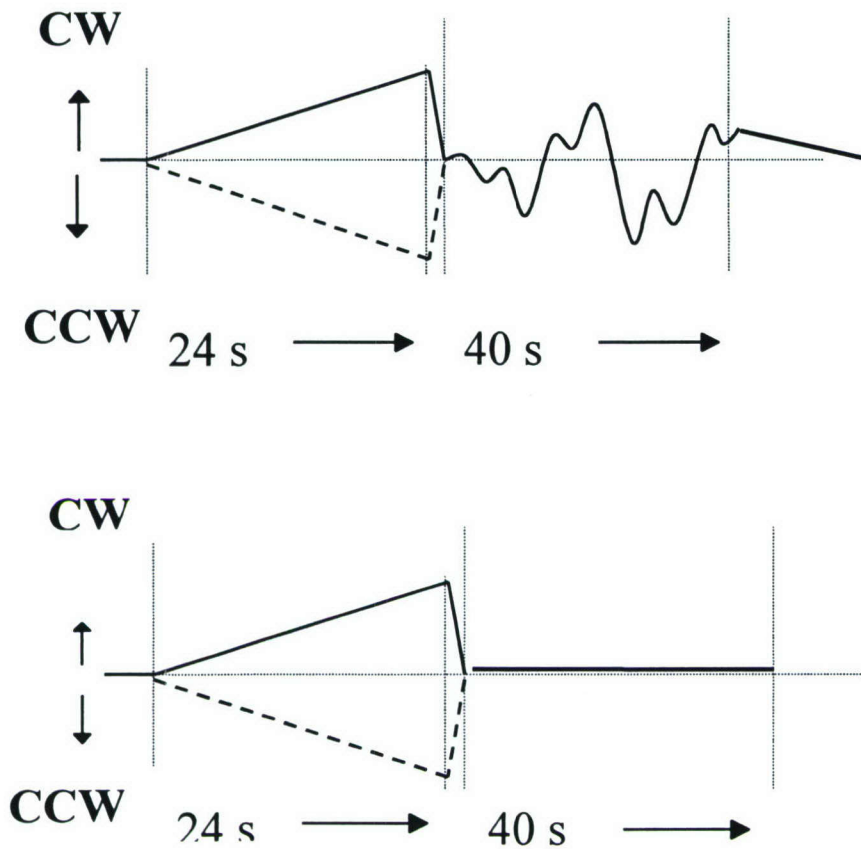
Figure 2. Schematic drawing of chair velocity (ω) and acceleration. In the first sequence, without intervention the participant is brought to a condition of disorientation, with a clockwise (CW) or counter-clockwise (CCW) rotation. In one of the two second sequences, random movements were added to the chair which the participant was required to cancel.

3.5 3-D Audio

Using stereo earphones, the NASA – Ames SLAB software system generated a brief burst of white noise along a horizontal plane at ear level (12, 18). A complete rotation produced a sound apparently traveling around the head.

3.5.1 Procedure

Four sessions were required of each participant. Each session was separated by a minimum of 24 hrs. During the first training session, two randomly selected perturbation patterns were presented to the chair for 60 s and the participant was required to cancel

the movements. At no time was the participant exposed to the somatogyral illusion. Four stimulus conditions were presented in the following order: a) Ctrl, where no tactile and audio stimulation was presented, b) tactile stimulation only, c) 3-D audio stimulation only, and d) both tactile and 3-D audio stimulation. For the first trial of each stimulus condition, room lights were illuminated and the door to the chamber was opened allowing the participant a view of the outer room. The participant viewed his/her effectiveness in nulling the random perturbations of the chair. The remaining trials were accomplished in the dark and vision was occluded. The participant was considered trained if he/she achieved twice during each trial and on two successive trials a cancellation error of 20°/sec or less for at least 10 seconds or received a maximum of four trials.

Each participant had one day of formal training and two test sessions. Formal training and testing followed the same procedure. The first phase generated the simulated somatogyral illusion, and the second phase, when instructed to do so, required the participant to stop or null the perceived rotations of the chair by rotating the cancellation knob in the opposite direction for a total of 40 sec, at the end of which time the chair was brought to a stop. Prior to the start of each trial, the participant was informed as to whether tactors, audio, both, or neither was to accompany the trial.

Each participant performed 8 trials per session. The trials consisted of each combination of perturbation (no, yes), tactile stimulation (belt: off, on), and 3-D audio (audio: off, on). The presentation order of the trials contained both counter-balancing and randomization to minimize the effects of direction (clockwise, counter-clockwise), perturbation types, fatigue, and learning. The perturbation, tactile belt, and audio levels were randomly assigned within a participant with

the following constraints to minimize order effects: a) each combination appears at most once in trials 1-2, once in trials 3-4, once in trials 5-6, and once in trials 7-8; b) a particular combination never follows another combination more than once, and c) the same factor level (e.g. 3-D audio) never appeared three times in a row in the same day.

After each trial the participants were asked to rate how successful they thought they were in reducing the movement of the chair, where 1 = not at all, 2 = rarely, 3 = moderately, 4 = for the most part, 5 = very successful. With the same rating scale after each test session day, they were asked how helpful they considered the tactile stimulation, 3-D audio, or both to be in reducing the movement of the chair.

A subject could stop the procedures by saying "Stop," or activate one of the two interrupt buttons located on the handholds. These buttons automatically cut power to the chair motor allowing for free rotation to a gentle stop.

Motion Sickness symptoms were evaluated using two different techniques. 1) Prior to and after each session participants were administered the MSAQ, the Motion Sickness Assessment Questionnaire (8), a standardized self-report survey assessing changes in four dimensions that included gastric, central, peripheral, and sopite symptoms; and 2) after each trial, an abbreviated version of a motion sickness symptoms scale was administered and participants identified either none, mild, moderate, or severe to the following items: stomach awareness, stomach discomfort, nausea, dizziness, warmth, spinning, drowsiness, sweating, salivation, and headache (9). Prior to being released from the study, participants were administered a battery of simple motor tasks to determine well-being and identify any residual motion sickness effects from the experimental procedure.

4.0 Results and Discussion

All data were analyzed using Repeated Measures ANOVAs. Figure 3 contains the mean cancellation errors (CE) and significance levels as a function of the experimental conditions.

4.1 Countermeasures

The interactions showed the effectiveness of the countermeasures. Tactile belt with perturbations showed a significant interaction, $F(1,9)$ 7.35, $p = 0.024$. From Figure 3, in the absence of perturbations to the chair the tactile belt showed a significant reduction in CE (21 deg/s). When perturbations were applied the effect approached significance ($p = 0.0612$). The tactile belt and 3-D audio showed a significant interaction, $F(1,9)$ 6.84, $p = 0.028$. Relying solely on vestibular inputs, a Mean CE of approximately 52% was found. The application of countermeasure stimulation from 3-D audio (36 deg/s), the tactile belt (29 deg/s), and both 3-D audio and belt (28 deg/s) significantly reduced the velocity of the chair's rotation.

4.2 Perturbations

The application of random movements to the chair significantly increased the CE (9 deg/s) as compared to no perturbations, $F(1,9)$ 5.83, $p = 0.039$).

4.3 Training

Overall, Test Session 2 showed a significant decrease (7 deg/s) in the Mean CE from that of Session 1, $F(1,9)$ 5.89, $p = 0.0382$. This reduction was not associated with specific improvements in the use of the tactile or audio countermeasures.
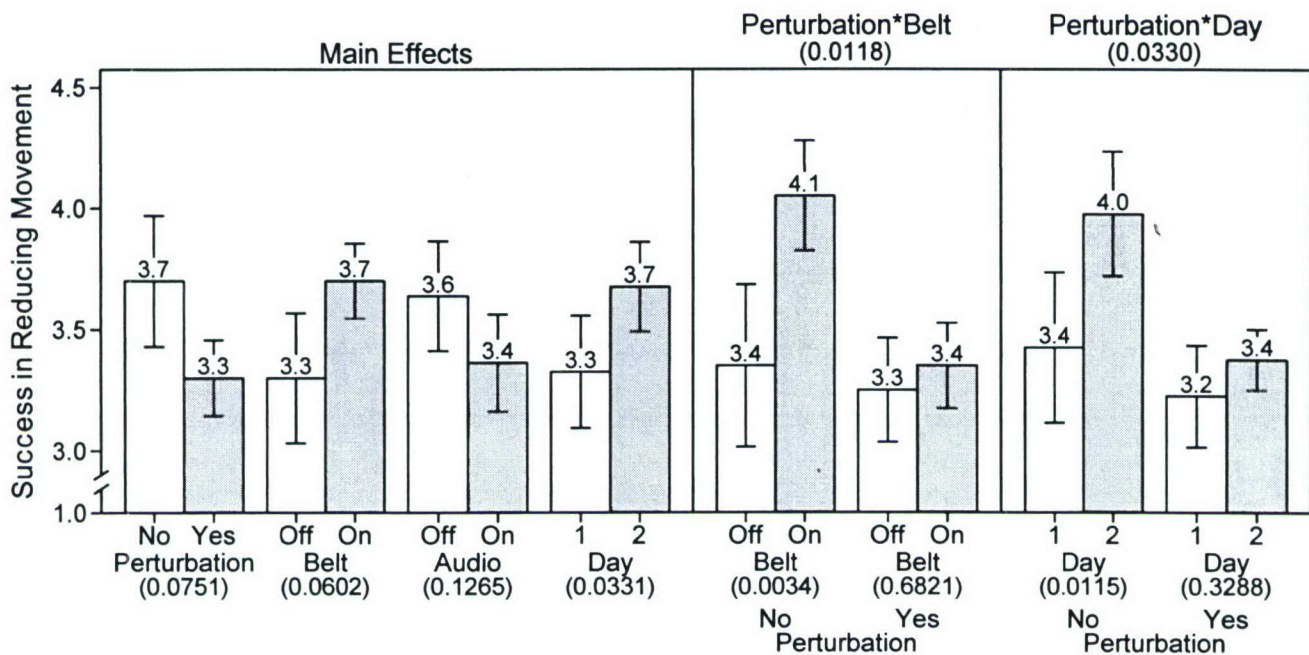
Figure 3. Mean cancellation error (± S.E.) for each combination of levels of perturbation, tactile belt, and audio for all main effects and significant interactions, p-values are directly above either main effect or simple main effect. For the perturbation x belt interaction, the simple main effect p-values for comparing perturbation were: belt off = 0.8640, belt on = 0.0007. For the audio x belt interaction, the simple main effect p-values for comparing audio were: belt off = 0.0072, belt on = 0.5942.

Figure 4 contains the mean successfulness ratings in nulling the movements of the chair.

Perceived success produced mixed results for the non-perturbation and perturbation trials. With

the non-perturbation trials, the tactile belt countermeasure produced the highest success rating

(M = 4.0). The lowest rating (M = 2.9) was associated with 3-D audio as a countermeasure.

However, 3-D audio as a countermeasure was successful in significantly reducing CE. When

relying solely on vestibular inputs, mean success rating (M = 3.7) of relatively successful was

not in agreement with actual performance. This latter finding suggests that even with tactile and

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3-D audio training, if they are not provided, a pilot may once again rely on erroneous vestibular
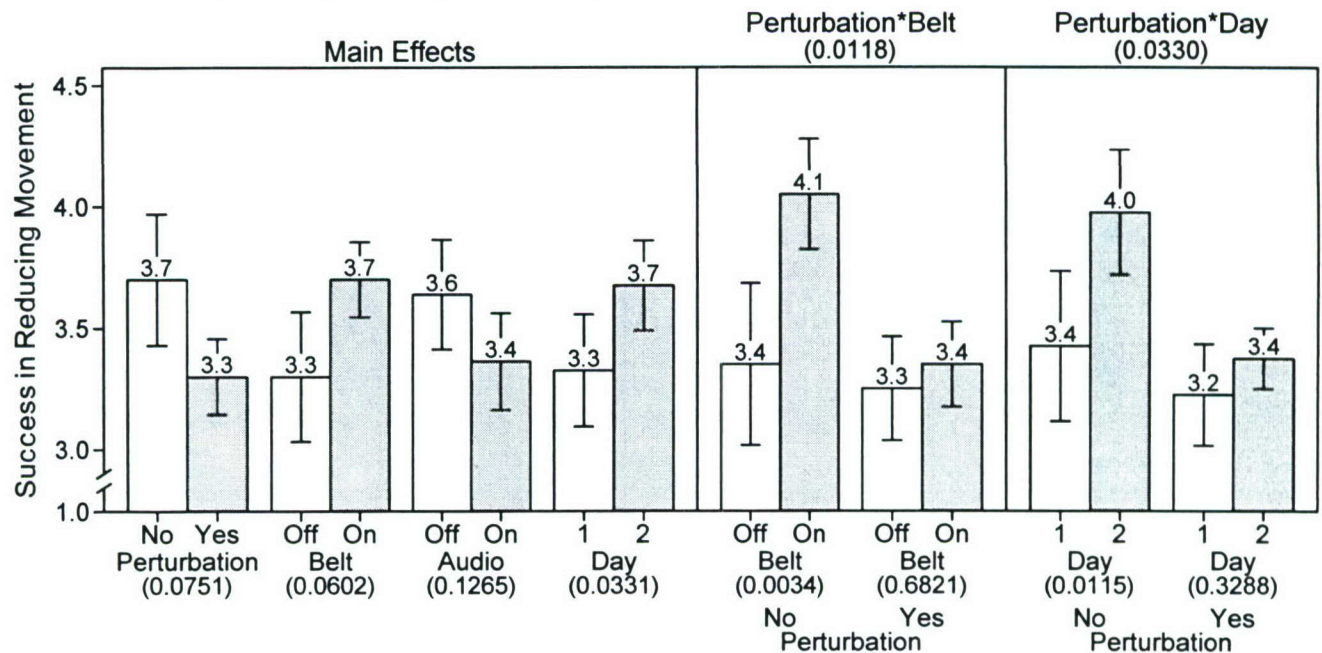

Figure 4. Mean success (± S.E.) in reducing the chair's movements for all main effects and significant interactions, for the perturbation x belt interaction, the simple main effect p-values for comparing perturbation were: belt off = 0.5652, belt on = 0.0260 and for the perturbation x day interaction, the simple main effect p-values for comparing perturbation were: day 1 = 0.4529, day 2 = 0051.

cues to control an aircraft. Overall, random perturbations were associated with lower success ratings in nulling the chair's movements.

End of session evaluation ratings of how helpful the countermeasures in controlling the chair's movements mirrored the individual trial ratings. A repeated measures analysis of variance found a significant different among tactile stimulation only (M = 4.1), 3D audio only (M = 2.8), and both (M = 3.9), $F(2,18) = 39.60$, $p = 0.0001$. Probability values from pairwise two-tailed t-tests using pooled error were: TS vs. Audio $p = 0.0001$, TS vs. Both $p = 0.0228$, Audio vs. Both $p = 0.0001$. Although both countermeasures were successful in reducing the CE, the tactile belt was viewed more helpful than either audio or both. When both were presented, 3-D audio was often described as distracting, annoying, and ignored.

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Figure 5 contains the weighted motion sickness symptom scores (MSS) obtained after

each trial with or without perturbations and the presence or absence of countermeasures. Main

effects for belt and audio; and interaction were significant, belt alone $F(1,9)$ 16.15, $p = 0.003$,

audio alone $F(1,9)$ 33.76, $p = 0.0003$, & both $F(1,9)$ 30.04, $p = 0.0004$. From Figure 5, symptoms

increased in the absence of audio and belt stimulation, but were virtually nonexistent when

countermeasures were present. Examining the individual symptoms showed that "spinning" was

the most commonly reported symptom. The main effects and interaction for the sensation of

spinning were essentially identical to that of MSS, belt $F(1,9)$ 22.5, $p=0.0011$, audio $F(1,9)$

41.07, $p = 0.0001$; both audio and belt $F(1,9)$ 33.39, $p = 0.0003$. Spinning accurately described

the chair's movements when relying on vestibular cues. This symptom dissipated shortly after
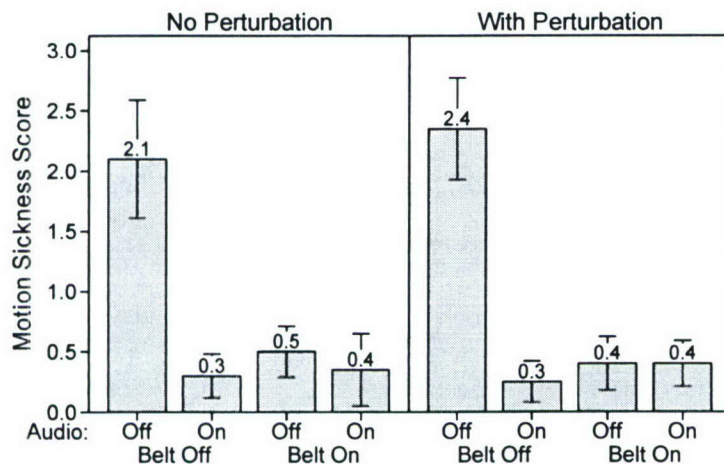
the end of the trial.

Figure 5. Mean motion sickness scores as a function of perturbations and countermeasures.

The MSAQ showed no difference between pre- and post-test motion sickness scores.

The four subscales, i.e., gastric, central, peripheral, and sopite, were essentially zero at the start

and end of the sessions.

The post–experimental procedure designed to identify residual signs of motion sickness failed to identify any participant displaying any signs, e.g., unsteady gait, swaying, light headedness, etc. All were released from the study without the need for any intervention.

5.0 Conclusions

We replicated the previous results when random perturbations were applied during the cancellation phase, i.e., without countermeasures, the chair rotated in the original direction at a velocity of 51 deg/s, confirming the simulated somatogyral illusion. Nulling the random perturbations of the chair was a difficult task to perform. During initial training several of our participants failed to reach the criteria and received the maximum number of trials. The addition of the perturbation training and test session trials permitted us to present the non-perturbation trials, which was more reflective of a classic somatogyral illusion. Interestingly, when vestibular sensations were the only source of information to reduce the illusion, CE was virtually identical with and without perturbations. However, in the absence of perturbations, when tactile stimulation was available, the CE was significantly reduced ($M = 22$ deg/s). In the previous research (4), results were analyzed for the first 20 s of a 40 s cancellation period. In the present study, using the 40 s period, without countermeasures, the illusion persisted for the 40 s period.

The 3-D audio countermeasure proved to be successful in reducing the velocity of the chair's rotation. However, the effectiveness of this countermeasure was not as appreciated as compared with tactile stimulation. This technique may increase its apparent effectiveness if a more meaningful audio stimulus were presented (1, 2). In the present experiment, white noise circled the head. If the stimulus contained meaningful verbal information, as to a voice identifying the attitude of the aircraft or conversation that circles the head, a more positive attitude may develop.

The present study suggests that additional training may not be necessary, although the effectiveness in controlling the chair's rotation was reduced somewhat (M=7 deg/s) from session 1 to 2. This CE reduction was not associated with an improvement in the use of the countermeasures, but only in the subjective confidence or success, especially with the tactile belt during non-perturbations. A pilot may believe he/she is not adequately trained, i.e., the belt is "not intuitive," but can still use the countermeasures effectively.

Even though our belt had fewer tactors and a greater separation between them then in the previous research, it appears that our increased granularity played only a minor role. It is possible that our placement about the waist may have generated a sensory saltation or "jumping rabbit" and hence reduced the need for additional tactors (7, 8, 14).

6.0 Recommendations

Our research supported previous research that in this procedure rotation about the vertical axis does not result in motion sickness (4, 5, 17). A rotating chair with a sudden stop had been used as a provocative test for motion sickness (10, 11). In these experiments the chair accelerated faster (20 deg/s), reaching a constant velocity (300 deg/s) rotated longer (30s), suddenly stopped, and reversed direction. When vision accompanied vestibular stimulation motion sickness symptoms were heightened (11). In the simulated somatogyric illusion vision was occluded, which may further reduce the probability of motion sickness. In the environment, visual cues of the interior of the cockpit are present, a sudden loss of altitude occurs, as well as a high state of physiological and psychological arousal. All would lead to heightened anxiety compounded by increased symptoms of motion sickness. The autogenic feedback training exercise (AFTE), commonly used for controlling/eliminating motion sickness was successfully used to reduce human error during emergency flying conditions (6). Wearing the AFTE vest

allowed the pilots to monitor and using biofeedback to reduce physiological arousal. From our findings, tactile vibrations and 3-D audio were effective and may be indirect mechanisms for reducing physiological and psychological arousal.

7.0 References

1. Begault, D.R., Wenzel, EM, & Lathrop, WB (1997) Augmented TCAS advisories using a 3-D advisory guidance system. Proceedings of the ninth international symposium. The Ohio State University, Columbus, Ohio.

2. Begault, D (1994) 3-D sound for virtual reality and multimedia. Cambridge, MA: AP Professional.

3. Benson, AJ (1988). Spatial disorientation--General aspects and common illusions. In: Aviation Medicine. 2nd ed. Ernsting J, Nicholson, AN, Rainford, King, P (eds) Butterworths and Co., Boston. 277-317.

4. Bos, JE, van Erp, J., Groen, EL, Hendrik, JV (2005). Vestibulo-tactile interactions regarding motion perception and eye movements in yaw. Journal of Vestibular Research, 15, 149-160.

5. Clark, B. & Stewart, JD. (1967). Vestibular and nonvestibular information in judgments of attitude and Coriolis motion in a piloted flight simulator. Aerospace Medicine, 38: 936-940.

6. Cowings, P.S., Kellar, MA, Folen, RA, Toscano, WB, & Burge, JD (2000?) Autogenic feedback training exercise and pilot performance: Enhanced functioning under search-and-rescue flying conditions. International Journal of Aviation Psychology, 11(3), 303-315.

7. Geldard, F.A. (1965). Sensory Saltation: Metastibility in the perceptual world. Lawrence, Erlbaum Associates, Hillsdale, NJ

8. Graybiel, A. (1969). Structural elements in the concept of motion sickness, Aerospace Med 40:351-367.

9. Graybiel, A, Lackner, JR (1980). A sudden-stop vestibulovisual test for rapid assessment of motion sickness manifestations. Aviat. Space Environ Med, 51(1) 21-3.

10. Lackner, JR & Graybiel, A (1979). Some influences of vision on susceptibility to motion sickness. Aviat Space Environ Med, 50(11) 1122-5.

11. McKinley, RL & Ericson, MA (1997) Flight demonstration of a 3-D auditory display. In Biaural and spatial hearing in real and virtual environments (Ch 13, 683-699). Gilkey, R.H/ &Anderson, TR, eds. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

12. Miller, JD (2001). Slab: A software-based real-time virtual acoustic environment rendering system. Proceedings of the 2001 International Conference on Auditory Display, Espoo, Finland.

13. Previc, F.H. & Ercoline, W.R. (2004) Spatial Disorientation in Aviation. Ch 1

14. Repperger, D Guzy, LT & Bowden, D. (2005). Possible spatial disorientation mitigation via electro stimulation sensory feedback, presented at the Aerospace Medical Association meeting, Orlando FL, May 2005.

15. Rupert, AH. (2000a). An instrumentation solution for reducing spatial disorientation mishaps. IEEE Engineering in Medicine and Biology, 19(2), 71-80.

16. Rupert, AH (2000b) Tactile stimulation awareness system: proprioception prostheses for sensory deficiencies. Aviation Space and Environmental Medicine, 71:A92-A99.

17. Van Erp, J (2005). Presenting directions with a vibrotactile torso display. Ergonomics, 48(3): 302-13.

18. Wenzel, E. & Miller, J. 3-D audio http://human-factors.arc.nasa.gov/SLAB,